The potential role of energy efficiency in the transition to a low carbon society – a critical scenario review

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Abstract

International consensus is growing that a transition towards a low carbon society (LCS) is needed over the next 40 years. The G8, the Major Economies Forum on Energy and Climate, as well as the Ad Hoc Working Group on Long-term Cooperative Action under the United Nations Framework Convention on Climate Change, have concluded that states should prepare their own Low-emission Plans or Low-emission Development Plans and such plans are in development in an increasing number of countries.

An analysis of recent long-term low emission scenarios for Germany shows that all scenarios rely heavily on a massive scale up of energy efficiency improvements based on past trends. However, in spite of the high potential that scenario developers assign to this strategy, huge uncertainty still exists in respect of where the efficiency potentials really lie, how and if they can be achieved and how much their successful implementation depends on more fundamental changes towards a more sustainable society (e.g. behavioural changes).

In order to come to a better understanding of this issue we specifically examine the potential for energy efficiency in relation to particular demand sectors. Our comparative analysis shows that despite general agreement about the high importance of energy efficiency (EE), the perception on where and how to achieve it differ between the analysed scenarios. It also shows that the close nexus between energy efficiency and non-technical behavioural aspects is still little understood. This leads us to the conclusion that in order to support energy policy decisions more research should be done on energy efficiency potential. A better understanding of its potential would help energy efficiency to fulfil its role in the transition towards a LCS.

Introduction

At the G8-Summit in Heiligendamm, Germany in 2007 the G8-leaders concluded that the ultimate goal of the UNFCCC should be put into operation by "consider[ing] seriously" to cut global GHG emissions by at least 50 % by 2050 (G8 Summit 2007). Since then, this long-term target has been reiterated and further defined on several occasions, e.g. at the G8 summit in L'Aquila and at the COP in Copenhagen. At COP 16 in Cancun the 2 °C target was made part of the official outcomes (UNFCCC 2010).

The results presented by the IPCC (Gupta et al. 2007, p. 776) make it clear that the target of cutting global emissions by more than half by the middle of this century means that industrialised countries need to reduce their 1990 emission levels by 80 to 95 % by 2050. In other words, the successful transition to a low carbon society needs to be achieved within the next four decades.

At the Major Economies Forum on Energy and Climate in L'Aquila, Italy, in September 2009 the leaders of those countries declared to prepare national "low carbon growth plans" (LCGP). The Council of the European Union welcomed the willingness of the participating countries to prepare LCGPs (Council of the European Union 2009, p. 2).

To date the United Kingdom and Japan have already prepared plans for progressing towards a Low Carbon Society[1] and other countries are following, e.g. the German Government announced an official GHG emissions reduction target for 2050 of -80 % vs. 1990 in the context of its recently published energy concept (BMU 2010). The EU Commission is in the process of publishing its energy roadmap for 2050.

GHG MITIGATION THROUGH ENERGY EFFICIENCY IN GLOBAL SCENARIOS

With regards to this growing international consensus on the necessity to achieve low carbon societies by the middle of the century, the question arises regarding the core strategies to be pursued. Current energy scenario studies on a global scale show that improving energy efficiency is one of the core strategies, if not the most important one, necessary for achieving ambitious CO_2 emission reduction targets[2].

Hanaoka et al. (2009) analyse more than 50 global GHG emission scenarios in relation to their core strategies for GHG emission reduction. For their comparison they use the information collected in the Emissions Scenarios Database (Morita and Lee 1998, Hanaoka et al. 2006)[3]. Most of the data stems from international model comparisons, such as those from the Energy Modeling Forum (Weyant 2004, De la Chesnaye and Weyant 2006) and the Innovation Modeling Comparison Project (Edenhofer et al. 2006). For a decomposition of GHG emission reductions they use an extended Kaya equation to identify the relevance of economic growth, energy intensity, carbon intensity of energy use and non-energy carbon emissions (Hanaoka et al. 2009, 99). Based on this analysis they conclude that, "energy intensity improvements play the most important role in reducing CO_2 emissions in the short term" and "the more stringent the stabilization level, the higher the required level of energy intensity improvement" (Hanaoka et al. 2009, 101). For the more stringent emission scenarios of IPCC-categories I to III they find an average annual energy intensity reduction of 2 %[4].

A comparison by the IPCC of different scenarios from four integrated assessment models (AIM, IMAGE, IPAC and MESSAGE), aiming at stabilization at low concentration levels (490–540 ppm CO_2-eq), leads to comparable results. In this instance, working with 2030 as the target year, energy efficiency is again the most significant strategy for reducing global CO_2 emissions in all models. In most of these models energy efficiency also remains the most important strategy when looking at the whole of the 21st century (see Ürge-Vorsatz&Metz 2009, 89).

Similar conclusions can be obtained from the energy scenarios in the recent Energy Technology Perspectives studies by the IEA (2008, 2010) and the energy [r]evolution scenario studies by Greenpeace and EREC (2007, 2010). The climate protection scenarios from these studies allocate 12.2 to 17.3 Gt of CO_2 or 36 to 43% of total GHG mitigation vs. reference to final energy efficiency. This is the most significant strategy in all four scenarios apart from the 2010 energy [r]evolution scenario (cp. annex).

However, in spite of the agreement between virtually all studies on the general importance of energy efficiency, there appears to be less of a consensus about how great the potential for efficiency improvements is in each demand sector. This will be demonstrated in this paper by an analysis of low carbon energy scenarios for Germany. The analysis shows that while total energy efficiency improves to a similar extent in all scenarios, the respective contribution of individual energy demand sectors varies considerably from scenario to scenario. This points to high levels of uncertainty regarding future energy efficiency potential. Future studies should attempt to reduce these uncertainties as more effective policy measures can be implemented once the areas for potential major (and low cost) energy efficiency improvements are properly identified.

In-depth analysis of energy efficiency in recent German low carbon energy scenarios

Energy scenarios have long been used by German policymakers as an instrument to support energy policy decision-making. Long-term energy scenarios have been used, for instance, by several Enquête Commissions of the German Parliament, such as "Protection of the Earth" I and II (1990 to 1998) and "Sustainable Energy Supply" (2000 to 2002). The 2002 report of the latter commission already aimed for an 80 % reduction of energy-related CO_2 emissions by 2050. Energy scenarios have also been used in the context of the so-called Energy Dialogue of the German Chancellor (2006 and 2007) and in the context of the German energy concept debate (2010). In this paper we will analyse a number of recent long-term low carbon energy scenarios.

Following an overview of the contexts and core targets of the scenarios, we provide an overview of their core strategies and the assumptions they make about the development of German final energy demand over the next 40 years. Final energy demand is then decomposed to obtain sectoral energy efficiency trends and the effects of aggregated sectoral energy service indicators.

OVERVIEW OF THE SCENARIOS ANALYSED

Within the past two years a number of long-term scenario studies commissioned by different stakeholders (Federal Ministries, environmental NGOs and large electricity suppliers) have attempted to explore the possible future development of the German energy system. All of these scenarios explicitly aim for a considerable reduction in energy-related CO_2 emissions[5] and most scenarios achieve reductions of 80 % or more by the middle of this century (vs. 1990).[6] Table 1 provides some key characteristics of the scenarios that we will be comparing.

1. e.g. Japanese "Action Plan for Achieving a Low Carbon Society"; the UK Low Carbon Transition Plan

2. see the comparative analyses by Hanaoka et al. (2009) and Ürge-Vorsatz&Metz (2009) as well as our own analysis of recent energy scenarios published by IEA and Greenpeace/EREC (Lechtenböhmer&Schneider 2009).

3. available under http://www-cger.nies.go.jp/scenario/index.htm

4. Here we only discuss "low carbon scenarios" (roughly) compatible with a 2 °C target and a global GHG-emission reduction vs. 1990 by at least 50 %, which would be roughly comparable to the lowest IPCC scenario categories I and II. For those however, the Emission Scenarios Database only contains a small number of studies. Furthermore, only 8 out of 20 available scenarios provide the necessary information on energy intensity. (cp. Hanaoka 2009, 98).

5. Some scenario studies (WWF 2009, Greenpeace 2009) also take account of GHG other than CO_2 and of non-energy related sources of CO_2.

6. The only exception is "Scenario 3" of the study commissioned by the four large German electricity suppliers (EnBW et al. 2009). Even though Scenario 3 is the study's most ambitious scenario with regards to climate protection, it achieves a reduction in energy-related CO_2 emissions of only 67 % by 2050 (vs. 1990).

Table 1: Overview of key characteristics of the compared scenario studies.

Lead Study 2009	Model Germany	Plan B (2009)	Energy concept scenarios	Energy Future 2050
• For BMU (2009) • By Nitsch, J. (DLR), Wenzel, B. (IfnE)	• For WWF (2009) • By Prognos AG & Öko-Institut	• For Greenpeace (2009) • By EU Tech	• For the federal government (BMWi&BMU) (2010) • By Prognos AG, EWI, GWS	• For EnBW, EON, RWE and Vattenfall (2010) • By Forschungsstelle f. Energiewirtschaft(FfE)
• Core targets: - GHG emission reduction by 2050 by 80% (vs. 1990) - 100% domestic reduction (but: import of RES electricity) - Phase out of nuclear energy according to law from 2002	**• Core targets:** - GHG emission reduction by 2050 by 95% (vs. 1990) - 100% domestic reduction (but: import of RES electricity) - Phase out of nuclear energy according to law from 2002	**Core targets:** - GHG emission reduction by 2020 by 40%; by 2050 almost zero - 100% domestic reduction - No Carbon Capture (CCS) - Phase out of nuclear energy by 2015	**Core targets:** - GHG emission reduction by 2020 by 40%; by 2050 by 80% - 100% domestic reduction (but: significant import of electricity from renewables and nuclear) - Prolongation of nuclear energy by 4 to 28 years	**Core targets:** - Describing likely development of German energy system under varying assumptions - No explicit emission reduction goal - No nuclear energy phase out; new nuclear plants allowed (in Scenario 3)

Sources: own synopsis based on scenario studies as given in 1st row

The Lead Study 2009 ("Leitstudie 2009") is an update to previous scenario studies for the German Federal Ministry for the Environment (BMU). A main focus of this study is the growth of renewable energy sources in the German energy system by 2050. The question about how energy demand will develop is less of a focus.

Model Germany ("Modell Deutschland") is a scenario study commissioned by WWF Germany, published in 2009. An ambitious goal of a 95 % reduction in GHG emissions by 2050 (vs. 1990 levels) is pursued. The study's two main policy scenarios that we examine in this paper ("Innovation Scenarios"), do not quite achieve this goal. However, GHG emissions are reduced by almost 90 %. The study's two Innovation Scenarios differ in the use, or not, of CCS technology in the power sector. However, the energy demand side of both scenarios is identical.

Also in 2009, Greenpeace published a low carbon energy report for Germany, called Plan B. It contains only one policy scenario, which achieves GHG emission reductions of 90 % (vs. 1990) without using CCS technologies.

The four big energy utilities in Germany (EnBW, EON, RWE and Vattenfall) commissioned another energy scenario study for the German energy system, called Energy Future 2050 ("Energiezukunft 2050"). In addition to a reference scenario (Scenario 1) two policy scenarios are developed. The more ambitious one of these (Scenario 3) is included in the comparison used in this paper. Scenario 3 explicitly includes behavioural changes but is still the only one of the scenarios examined here that fails to reduce energy-related CO_2 emissions by 80 % or more (vs. 1990) by the middle of the century, achieving instead a reduction of just below 70 %.

Finally we also include Scenario II B from the energy scenario study commissioned by the German Federal Government in advance of finalising its energy concept, which was released in autumn 2010. One of the main targets of these scenarios, as stipulated by the German government, is a reduction in GHG emissions of 85 % by 2050 (vs. 1990). Scenario II B assumes that nuclear plants continue to operate for twelve years longer than Germany's now reversed phase-out regulation. However, on the energy demand side the study's various policy scenarios are quite similar.

All of the scenarios compared in this paper are policy scenarios that explicitly assume that various climate protection measures will be put into force during the coming decades. We do not analyse so-called reference scenarios (or business-as-usual scenarios), which assume that no additional climate policy measures will be implemented. While the comparison of reference scenarios with alternative scenarios can reveal the "policy gap" that additional policy measures need to fill, analysing this policy gap is not the goal of this paper. Instead, we focus on the *total* energy efficiency and energy savings that can potentially be achieved in the various scenarios between today and 2050, regardless of the question about the extent of additional policy measures needed.[7]

The model approaches used to reproduce the energy system are quite similar in all the scenario studies analysed. In this paper the model structure used by Prognos AG (see WWF 2009) and FfE (see EnBW et al. 2009) will be used as examples. Here energy demand is calculated bottom up by sectoral models, i.e. there is one sub-model for each of the four sectors - households, commerce, industry and transport. Energy balances for each sector are set up for a base year while final energy is further allocated among subsectors (e.g. branches of industry). Simultaneously, the demand for energy services is

7. In addition, one of the scenario studies we are analysing (BMU 2009) does not contain a reference scenario. Furthermore, reference scenarios are often difficult to compare as many of them lack a clear answer to the question about what exactly constitutes "no additional climate policy".

Table 2: Key Indicators of Recent Low Carbon Energy Scenarios for Germany.

Scenarios	Key indicators for 2050						
	---------Overall---------				-------Electricity generation[a]-------		
	Avg. annual GDP growth rate (2010-2050)	Change in avg. annual final energy intensity (2010-2050)[c]	Energy-related CO_2 emissions (vs. 1990)[b]	Share of renewable energy in primary energy supply[d]	Share of renewable energy[e]	Share of nuclear energy	Share of electricity from fossil fuel plants with CCS
Actual figures for 2009	-	-	- 26%	9%	16%	23%	0%
Lead Scenario (BMU 2009)	1.2%	- 2.0%	- 80%	50%	85%	0%	0%
Innovation Scenario without CCS (WWF 2009)	0.7%	- 2.7%	- 91%	76%	97%	0%	0%
Innovation Scenario with CCS (WWF 2009)	0.7%	- 2.7%	- 90%	59%	73%	0%	22%
Plan B (Greenpeace 2009)	n.s.	n.s.	- 97%	90%	100%	0%	0%
Scenario 3 (EnBW et al 2009)	1.3%	- 2.4%	- 68%	36%	~ 50%	~ 12%	~ 3%
Energy Concept Scenarios (BMWi 2010)[f]	0.8%	~ - 2.1%	- 85 %	~ 50%	77 – 81%	0 – 2.6%	8 – 9%

Sources: AG Energiebilanzen 2011, UBA 2011, Lechtenböhmer et al. 2010, sources of scenario studies as given in 1st column

The studies for BMU and Greenpeace both describe one policy scenario each. The study commissioned by WWF describes in detail two different policy scenarios, which both achieve very similar CO_2 reductions by 2050. One of them assumes that carbon capture and sequestration (CCS) technologies are introduced in the electricity sector, while the other scenario assumes that these technologies are not introduced in this sector. The study for EnBW et al. contains two policy scenarios of which only the more ambitious one is documented here.

Footnotes: a: Not including secondary electricity generation (i.e. electricity generation from storage plants). b: All CO_2 reductions are achieved domestically, meaning within Germany and without importing emission rights. c: Final energy intensity is defined here as final energy demand per unit of GDP. d: The given shares of renewables in primary energy production are calculated based on the common physical energy content method. e: Share includes import of electricity from renewable sources in some of the scenarios. Further (electricity-only) scenario studies have been released recently (SRU 2010, UBA 2010), describing an all-renewable electricity supply in Germany by 2050. f: The study contains 8 target scenarios describing different variants on how to achieve significant emission reductions. The given values represent average values or ranges of those scenarios.

computed bottom up. The use of several individual technologies (with specific energy consumption) is estimated in order to meet energy service demand. The model calculates future energy service demand according to socio-demographic data, the latter cited from external economic or demographic models. Technology development is filed in a database and market shares are estimated taking into account efficiency potentials, technical lifetime and total costs. In the last step the model calculates final energy demand.

Table 2 gives key indicators of the energy system as a whole and the electricity system in particular for the scenarios analysed. They show the respective relevance of key strategies in the different scenarios. Table 2 demonstrates that in spite of differences in detail the general view of a future German low carbon energy system is fairly consistent: high and sustained final energy intensity improvements of 2.1 to 2.7 % annually combined with a significant expansion of renewable energy supply from the current 9 % to 50 % or more of TPES are regarded as prerequisites for a low carbon strategy[8]. Electricity generation in particular will be converted almost completely to renewable sources, dwarfing the other low carbon options such as nuclear or fossils with CCS. However, the less optimistic scenario of the study commissioned by the electricity utilities shows that there is still considerable debate about how – and if – such a conversion will be feasible.

The comparison shows that all scenarios expect high rates of overall final energy efficiency improvements over the coming forty years. In all scenarios final energy efficiency is one of the two major strategies to decarbonise the German energy system. Furthermore, the significant efficiency gains, which lead to an absolute decoupling of economic growth and energy use, contribute to the rapid increase in the share of renewable energy sources, which is the second core strategy in all the scenarios.

METHODOLOGY

In this paper we will provide an in-depth analysis of the assumptions that the studies make about energy efficiency. To achieve this, we decompose the energy intensity reductions by five (sub-)sectors: residential, commercial, industrial, passenger transport and freight transport. Data for those five sectors was available in most of the studies compared.

As most of the studies analysed here do not provide detailed information on final energy intensity, this data had to be calculated[9]. As a common basis for this analysis we look at final energy use in the four main energy demand sectors: residential, commercial, industrial and transport (the latter being differentiated between passenger and freight transport). For those sectors we determine the following key indicators as simplified representations of the "energy services" delivered:[10]

- Population (cap; for the residential sector)
- Commercial value added (VA_c; for the commercial sector)
- Industrial value added (VA_i; for the industrial sector)

8. As a comparison, between 1990 and 2009 energy productivity in Germany increased on average by 1.8 %. However, throughout the 1990s, the increase was considerably higher, by up to 2.4 %.

9. In particular, WWF 2009 gives a differentiated decomposition analysis of its scenarios. However, comparable data is not given in the other studies.

10. In mathematical terms this is the denominator for the energy demand in that sector.

Table 3: Absolute and relative CO_2 emission reductions between 2010 and 2050 by strategy in German energy scenarios.

Scenario	CO_2 emission reductions by strategy							
	Total (in Mt CO_2/a)				Share			
	Reduction in final energy demand	Expanded use of renewable energies	CCS	Fuel switch and power plant efficiency	End use energy efficiency	Renewable energies	CCS	Fuel switch and power plant efficiency
Lead Scenario (BMU 2009)	215	291	0	50	39%	52%	0%	9%
Innovation Scenario without CCS (WWF 2009)	286	364	0	12	43%	55%	0%	2%
Innovation Scenario with CCS (WWF 2009)	251	251	100	51	38%	38%	15%	8%
Plan B (Greenpeace 2009)	246	421	0	1	37%	63%	0%	0%
Scenario 3 (EnBW et al. 2009)	229	190	20	26	49%	41%	4%	6%
Energy Concept Scenarios (BMWi 2010)[f]	233	277	22	48	40%	48%	4%	8%

In order to assign CO_2 reductions to single strategies, as a first step the reductions achieved through the use of CCS (where applicable) and through changes in the CO_2 intensity of traditional primary energy sources ("fuel switch and power plant efficiency") were determined. The remaining share (which is at least 88% in all but one scenario) of emission reductions achieved from 2010 to 2050 was allocated to the strategies "reductions in final energy demand" and "expanded use of renewable energies". In order to isolate the effect of final energy demand reductions it was assumed that the energy supply system would remain the same (equal CO_2 emissions per unit of final energy demand) while to isolate the effect of renewable energy expansion, final energy demand was assumed to remain constant. Both these calculations overestimate each strategy's CO_2 reductions, as together they would make up more than 100% of CO_2 reductions. Therefore the two strategies' individual contribution as given in Table 3 was determined by keeping the relation between the two strategies constant while reducing their combined impact so as to be in line with the overall reduction contribution remaining after accounting for CCS and fuel switch.

Source: own calculations based on data from the studies mentioned

- Passenger kilometres (pkm; for passenger transport)
- Tonne-kilometres (tkm; for freight transport)

For the overall decomposition of the final energy demand projected in the studies we use the following extended Kaya equation:

$$FE = cap \bullet \left(\frac{GDP}{cap} \bullet \left(\frac{VA_i}{GDP} \bullet \frac{FE_i}{VA_i} + \frac{VA_c}{GDP} \bullet \frac{FE_c}{VA_c} + \frac{tkm}{GDP} \bullet \frac{FE_{G\&F}}{tkm}\right)\right)$$

$$+ cap \bullet \left(\frac{m^2}{cap} \bullet \frac{FE_{res}}{m^2} + \frac{pkm}{cap} \bullet \frac{FE_{pt}}{pkm}\right)$$

FE = Final energy use; $FE_{i\ c\ res\ pt}$ G&F = Final energy use in industry, commercial sector, residential sector, passenger transport, freight transport

In the equation the energy service indicators are given as intensities relative to GDP or population and the GDP is given per capita as a rough indicator for the welfare growth.

TRENDS IN FINAL ENERGY DEMAND BY DIFFERENT SCENARIOS

Before looking at the details in the scenarios regarding energy intensity, we provide an overview of the development of total final energy demand (Figure 1) and on the changes in final energy demand in each sector between the studies' base years (2005, 2007 or 2008) and the year 2050 (Figure 2).

Figure 1 shows that all the scenarios assume a considerable decrease in total final energy demand over the coming four decades. However, the reduction in final energy demand happens faster and is much more pronounced in the scenarios by WWF and Greenpeace (-58 and -54 % respectively) than in those by BMU and EnBW et al. (-33 % and -40 % respectively). The scenario for BMWi (2010) takes an intermediate position.

By showing the scenarios' final energy demand development by demand sector, Figure 2 points at further differences. While in both the residential and commercial sectors all scenario studies seem to share the general view that there is the potential to reduce demand considerably, by some 40 to 70 %, expectations regarding demand reductions in the industry and transportation sectors vary greatly. For the industrial sector EnBW et al. even expects final energy demand to be 20 % *higher* in 2050 compared to the base year, while the other scenarios expect decreases ranging from 25 to 53 %. In transportation three scenarios foresee a final energy demand reduction of around 30 to 40 %, while two other scenarios (Greenpeace and EnBW et al.) see much stronger reduction potentials of around 75 %. Such significant reductions are based, to a large extent, on assumed high shares of electric vehicles as well as on behavioural changes in these scenarios. Structural changes between the four demand sectors play an insignificant role in overall energy demand reductions.

In order to better understand the underlying reasons for the predicted demand reductions and the differences in the scenarios, it is necessary to further analyse the reasons for the changes in final energy demand. As final energy demand results from two main effects, the development of the energy service demand and the energy intensity of the technologies and appliances that deliver the energy services, in the next part of this paper we differentiate the scenarios by these two factors. Due to data limitations, however, we had to define one aggregated indicator for the energy service demand per sector and one aggregated indicator for energy intensity.

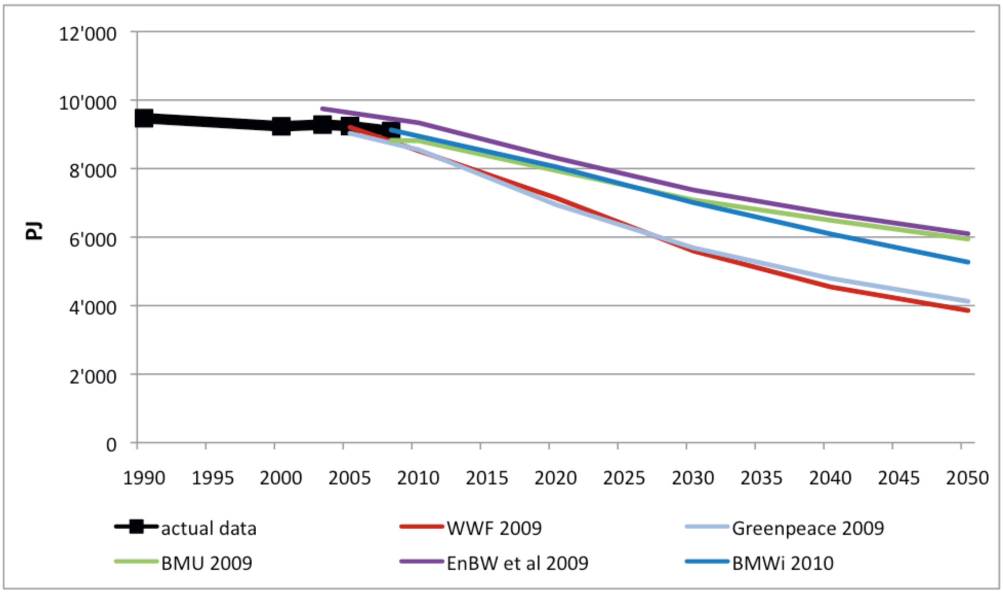

Figure 1: Total final energy demand in Germany between 1990 and 2050 according to different scenarios (own calculations).

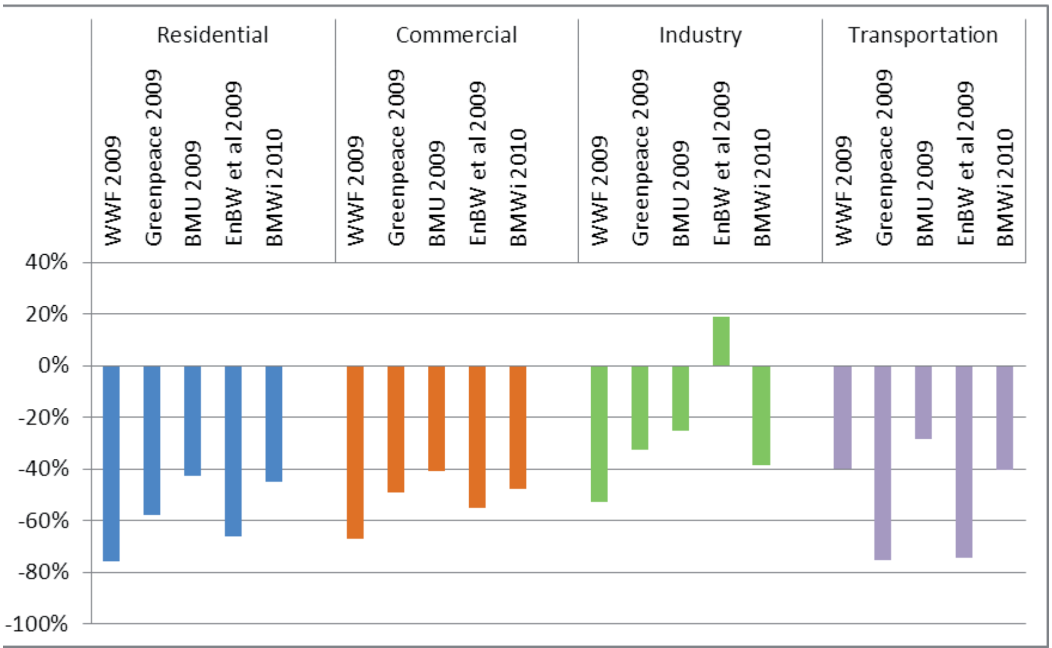

Figure 2: Change in final energy demand by demand sector between base year (2005, 2007 or 2008) and 2050 according to different scenarios (own calculations).

AGGREGATED SECTORAL ENERGY SERVICE INDICATORS

Figure 3 provides data for the aggregated energy service indicators per unit of GDP for the industrial, commercial and goods & freight transport and per capita for the residential and passenger transport sector. A comparison of the assumptions in the different studies illustrates that already the first indicator, GDP per capita, shows different growth rates between the scenarios. WWF and BMWi assume a low growth of 1.1 % per year on average and, notably, the most recently released study by BMWi takes into account the effects of the economic crisis with low growth rates over the next two decades, which slightly recover afterwards. BMU uses higher growth rates for the next two decades. EnBW et al., however, is overall much more optimistic than the other studies, assuming an average per capita GDP growth of 1.6 % per year.

With regards to the sectoral energy service indicators, in the residential sector all studies predict rather similar growth rates of residential living space of 0.5 % per year. In the transport sector, however, the expectations differ widely between the scenarios. While three of the scenarios expect no significant changes in passenger-km per capita, the scenario from the EnBW et al. study – which is the only scenario that explicitly assumes major behavioural changes to reduce traffic – assumes a high rate of passenger transport intensity reduction (1.4 % per year).

In freight transport, BMU and EnBW et al. expect a decreasing intensity with decline rates of 0.4 and 0.6 % per year respectively. On the other hand, the scenario of the BMWi study,

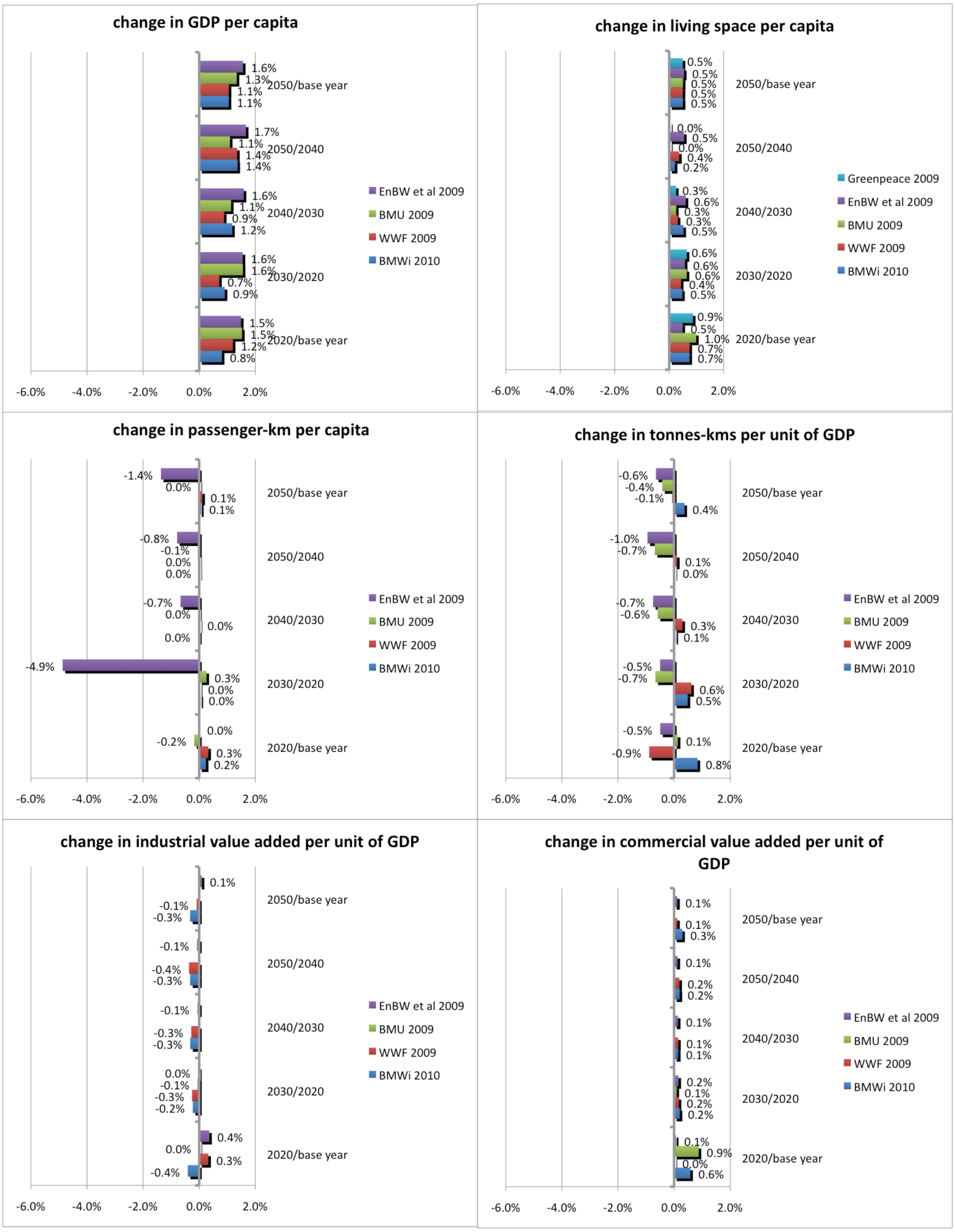

Figure 3: Activity per capita/per GDP changes (p.a.) in different demand sectors for the compared studies (own calculations) (Studies in descending order: (Greenpeace 2009, only for living space) EnBW et al. 2009, BMU 2009, WWF 2009, BMWi 2010).

predicts an increase in energy intensity of freight transport of 0.4 % per year. In the WWF scenario no major intensity changes occur in freight transport when looking at the entire period. For industrial and commercial value added per unit of GDP the scenarios show a similar picture. Industrial activities grow at a slightly lower rate than GDP. On the other hand, non-industrial sectors profit from structural changes with growth rates slightly above average. Again EnBW et al. has a different perspective here. With comparable relative growth of VA per GDP the study assumes no structural change on this level; an effect that can at least partly be explained by the study's base year of 2003 and the impacts since then.

In general these trends in the aggregated energy demand indicators per sector provide an initial explanation for the higher

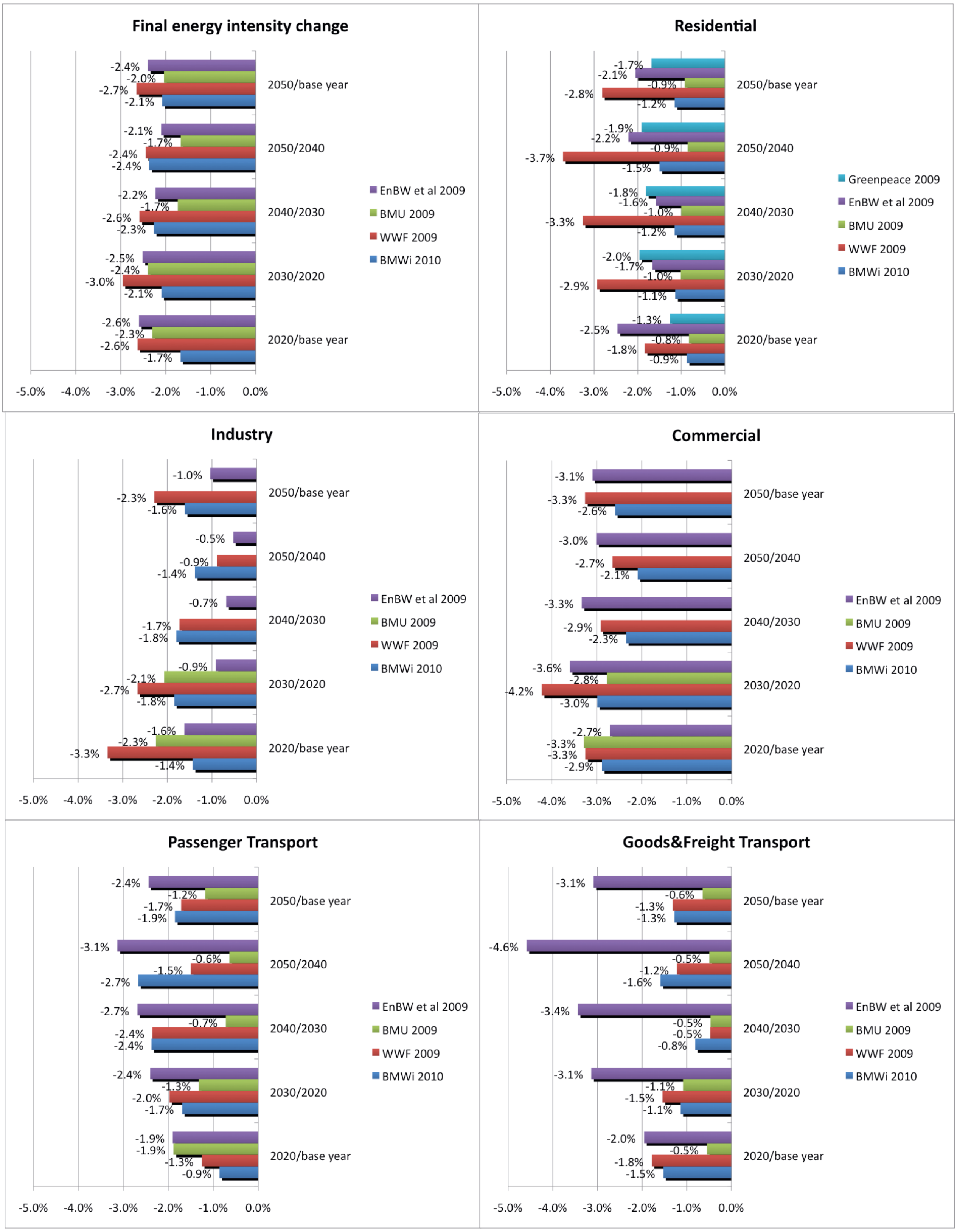

Figure 4: Energy intensity changes in different demand sectors for the compared studies (own calculations) (Studies in descending order: Greenpeace 2009 (only for residential), WWF 2009, EnBW et al. 2009, BMU 2009, BMWi 2010).

energy demand of the scenario by EnBW et al. for the industrial sector and the lower demand in the transport sector.

ASSUMPTIONS ON DEMAND SIDE ENERGY EFFICIENCY

Figure 4 compares four (in one case five) of the five selected scenarios with regards to final energy intensity change in the five sectors.

Overall, WWF and EnBW et al. are quite close with average annual intensity reductions of 2.7 and 2.4 % respectively. The studies for BMU[11] and BMWi are less optimistic with annual intensity reductions of 2.0 and 2.1 % respectively.

However, when it comes to energy intensity changes by sector, the differences between the studies are more pronounced. Major differences are in freight transport, where EnBW et al. expects reductions of 3.1 % per year while WWF and BMWi expect only 1.3 % and BMU (0.6 % per year) only a fifth of the levels predicted by EnBW. Likewise in the residential sector the studies expect very different energy intensity reductions (expressed as final energy demand per capita), ranging from -0.9 to -2.8 % per year. For the industrial sector the differences are also considerable, while in the commercial and the passenger transport sectors the studies' expectations of energy intensity reductions are more in line with one another than in the other sectors. Taking into account the temporal disaggregation, some rough common trends between the scenarios in all sectors occur, but significant differences are also evident - not only in the expected level of energy intensity reduction but also partly in the timing. Overall, the studies expect high rates of energy intensity reduction during the current decade until 2020 and most of the studies expect a further slight increase in the following decade between 2020 and 2030. After that three of them predict a slight decrease in the rate of intensity reduction until 2050. In the residential sector, WWF and BMWi expect continuously increasing rates of energy intensity decline, while BMU expects rather stable and comparatively low improvement rates of slightly less than 1 % per year.

RESULTS: REDUCING ENERGY SERVICES OR INCREASING ENERGY EFFICIENCY?

Table 4 compares all five scenarios with regards to one structural variable for every sector as an indicator of the sectoral energy service demand growth over the whole scenario period and their respective improvement of energy intensity as an indicator for the development of sectoral energy efficiency.

Taking into account the interplay of energy service demand projections and of energy intensity reduction as given in Table 4, again significant differences between the scenarios become apparent. In particular, the scenario in the study for EnBW et al. shows strong deviations from the other scenarios in relation to both energy services and energy intensity development.

While BMWi, BMU and WWF all expect an average growth of energy service demand of about 0.4 % per year, EnBW et al. expects a growth rate almost twice as high (0.7 % per year). This is mainly due to the fact that the study expects very high VA growth in industry; the growth rate here is about double the rate of the other studies' scenarios. The same is true for the growth rates in the commercial sector. For passenger transport, however, EnBW et al. expects the greatest decrease in energy service of all the studies compared and for freight transport they have the lowest growth rate together with BMU. Compared to past trends, however, all the scenarios predict a significant slowing down of growth rates of energy service demand.

Concerning energy intensity, of all the studies considered EnBW et al. expects the fastest decrease in the transport and commercial sectors and a high reduction rate in the residential sector. Only in the industrial sector is their expectation of an intensity reduction of 1 % per year the lowest of all the studies and significantly below the intensity decreases that the study projects for other sectors. As a result, EnBW et al. foresees the most significant decreases in final energy demand compared to the other studies across all sectors apart from industry.[12] Here they expect a demand growth in spite of a decrease in energy intensity. Together with the assumption of a high level of energy service growth, this effect overcompensates all other effects. For this reason the EnBW scenario expects overall final energy demand to decrease at the second lowest rate of all scenarios – in spite of the second highest efficiency growth rates.

The most optimistic scenario, with an expected decrease in energy intensity of 2.3 % per year, is the scenario by WWF. In the industry and residential sectors the expectations regarding efficiency improvements are significantly higher than in all other studies, while for the other sectors WWF is more or less in line with the other studies. Due to similar assumptions aboout energy service demand compared with BMWi and BMU this also results in the highest decrease of final energy demand - by 1.9 % per year.

The most pessimistic scenario is also the oldest one – by BMU in 2009. This update of previous studies generally assumes the lowest rates of energy efficiency improvement in every demand sector. Overall energy intensity reduction is expected to be only 1.3 % per year until 2050, or slightly less than reported over the last two decades.

Overall we find that the projections on energy service demand trends are relatively similar in three of the studies while one (EnBW et al.) differs, particularly for the industry and commercial sectors. All scenarios assume that growth rates of energy service demand will be significantly lower than in the past.

With regards to the expectations of energy efficiency there is one optimistic study assuming 2.3 % per year of final energy intensity reduction, one pessimistic scenario (1.3 %) as well as two intermediate studies (1.7 and 1.8 % per year respectively). This means that all but one study assume a significant increase of historical rates of energy efficiency improvement. Overall, this means there is one optimistic scenario (WWF) that predicts a 1.9 % per year overall final energy demand reduction, one intermediate scenario with a reduction of 1.3 % per year (BMWi) and two rather moderate ones with a demand reduction of about 1% per year (BMU and EnBW et al.). These differ-

11. In the case of BMU (2009) the period under consideration is 2008 – 2030. BMU 2009 does not provide any data for sectoral economic performance. GDP data given there relies on older studies (BMWi 2007; BMWi 2005), which indicate data for sectoral performance by 2030. The BMWi (2007, 2005) data was applied in our own calculations.

12. The only exception is the WWF scenario, which expects greater final energy demand reductions in the residential and commercial sectors than EnBW et al.

Table 4: Energy intensity and energy service indicator change by sector for 4 scenarios by 2050.

In % per year	*Historical 1990 - 2008*	BMWi 2010	WWF 2009	BMU 2009	EnBW et al 2009
Residential					
ES: population growth	*0.2%*	-0.3%	-0.3%	-0.2%	-0.2%
EE: change in final energy intensity	*0.1%*	-1.2%	-2.8%	-0.9%	-2.1%
NE: final energy demand change	*0.3%*	-1.4%	-3.1%	-1.1%	-2.3%
Commercial					
ES: growth in gross value added	*1.4%*	1.0%	0.9%	0.9%	1.5%
EE: change in final energy intensity	*-2.6%*	-2.5%	-3.3%	-1.5%	-3.2%
NE: final energy demand change	*-1.2%*	-1.5%	-2.4%	-0.6%	-1.7%
Industry					
ES: growth in gross value added	*1.1%*	0.5%	0.7%	0.7%	1.4%
EE: change in final energy intensity	*-1.8%*	-1.6%	-2.3%	-1.1%	-1.0%
NE: final energy demand change	*-0.7%*	-1.1%	-1.6%	-0.4%	0.4%
Passenger Transport					
ES: growth in passenger-km	*1.1%*	-0.2%	-0.2%	-0.2%	-0.8%
EE: change in final energy intensity	*-1.4%*	-1.9%	-1.7%	-1.2%	-2.4%
NE: final energy demand change	*-0.3%*	-2.0%	-1.9%	-1.4%	-3.2%
Goods&Freight					
ES: growth in tonne-kms	*3.4%*	1.2%	1.4%	0.7%	0.7%
EE: change in final energy intensity	*-1.6%*	-1.3%	-1.3%	-0.5%	-3.1%
NE: final energy demand change	*1.8%*	-0.1%	0.1%	0.2%	-2.4%
Total					
ES: Weighted energy service demand *)	*1.1%*	*0.4%*	*0.4%*	*0.4%*	*0.7%*
EE: change in final energy intensity	*-1.4%*	*-1.7%*	*-2.3%*	*-1.3%*	*-1.8%*
NE: final energy demand change	*-0.3%*	*-1.3%*	*-1.9%*	*-0.9%*	*-1.1%*

*Source: own calculations from the studies mentioned (ES: growth of aggregate energy service indicator; EE: energy efficiency effect = energy intensity reduction per unit of energy service; NE: net effect = final energy demand growth; – no data available) *) sectoral growth rates weighted with share of final energy demand in 1990 for history and 2008 for scenarios.*

ent conclusions result, however, from quite different assumptions.

Compared to the historic development almost all scenarios agree that the slowing down of energy service demand growth from 1.1 % per year to 0.4 % (or 0.7 % in the EnBW et al. study) is the most important effect .The rate of energy intensity improvement will either remain roughly at historical levels (in the case of the BMU study) or energy intensity will decrease by a further 0.3 or 0.4 percentage points in the BMWi and EnBW et al. studies, or by a further 0.9 percentage points in the WWF study. These changes combine in the scenarios to lead to a significant acceleration in final energy demand reduction from 0.3 % per year (historic) to values of between 0.9 and 1.9 % per year.

As a second step in comparing these values we combined the minimum assumptions for energy service demand and energy intensity as well as the respective maximum assumptions across all the sectors. That revealed a range of between 2.5 and 0.3 % in annual final energy demand reduction: 2.5 % per year if for every sector the lowest energy service demand trend and the most optimistic efficiency assumption is combined or only 0.3 % per year (equivalent to the historical value) if the highest service demand and most pessimistic assumptions about energy efficiency are combined. This experiment shows that the WWF scenario is optimistic but still somewhat below the theoretical range.

Conclusion

Increasing final energy efficiency above historical rates is a core strategy in almost all scenarios available on a global or national level. However, in spite of this unanimous finding (or rather this shared assumption), in all the scenario studies there are significant differences when examining energy demand in more detail.

Through an analysis of recent low carbon energy scenario studies for the relatively thoroughly studied country of Germany, we try to shed some light on this important issue. By comparing five studies presented in 2009 and 2010 by different scientific institutes, and commissioned by different stakeholders, definite consensus is yet again evident about the importance of energy efficiency as final energy intensity reduction (per unit of GDP) is increased from historical rates of 1.8 % per year to a range of 2.1 to 2.7 % per year over the next 40 years. This agreement, however, partly masks the differences in detail between the studies. With regards to energy service demand by sector and related energy intensity we find a significant range between the most optimistic and the most pessimistic study.

The scenarios, however, roughly agree that both effects combined, i.e. reduced growth of energy service demand and a (slight) increase of energy efficiency vs. historical values, will result in a significant acceleration of final energy demand reduction.

It must, however, be noted that this analysis is still very aggregated with regards to the modelling detail of the studies analysed and with the simplification of only one aggregated energy service indicator per sector. Here further studies and more in-depth comparisons of studies, as well as a harmonisation of the presentation of scenario study details, are necessary to enable a deeper understanding.

It was the aim of this paper to shed light on the question of whether or not the significant increases in final energy efficiency that many international and national studies see as core strategy for achieving a low carbon society might be realistic. By comparing five German scenario studies on a sectoral level we have demonstrated that there are still significant differences between the studies, which emphasises the need for further analyses of the real potential of energy efficiency, as well as for further improvements in the comparability of scenario studies.

However, our analysis also shows that the expected high reduction of final energy intensity per unit of GDP appears to be credible - at least in the case of Germany. A significant finding is that the scenarios all rely on a slowing down of energy service demand which, at the same time, means that while energy efficiency needs to improve faster than in the past, future improvements do not need to be extreme. Our analysis did not reveal any major weaknesses in the scenarios regarding energy demand. The scenarios are ambitious but in general do not seem to make unrealistic or extreme assumptions.

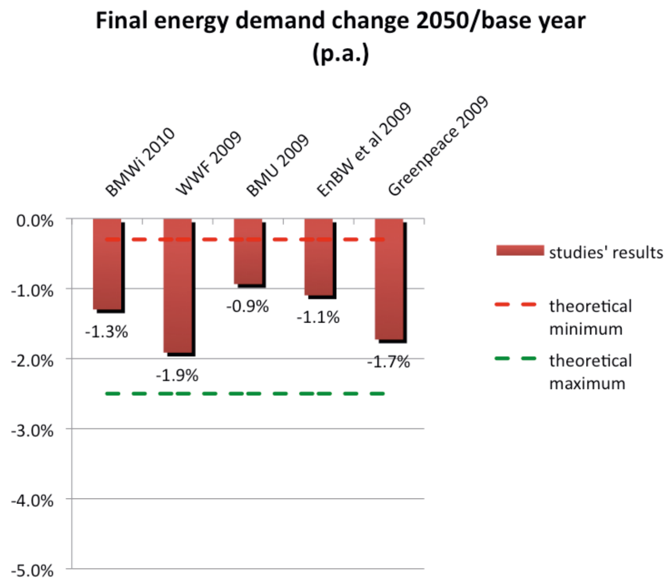

Figure 5: Final energy demand change ranges (own calculations).

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